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INTRODUCTION TO JUNE 1987 ISSUE OF THE CEEE TECHNICAL PROGRESS BULLETIN

This is the seventeenth issue of a quarterly publication providing information on the technical work of the National Bureau of Standards Center for Electronics and Electrical Engineering. This issue of the CEEE Technical Progress Bulletin covers the fourth quarter of calendar year 1986.

Organization of Bulletin: This issue contains abstracts for all Center papers released for publication by NBS in the quarter and citations and abstracts for Center papers published in the quarter. Entries are arranged by technical topic as identified in the table of contents and alphabetically by first author under each subheading within each topic. Unpublished papers appear under the subheading "Released for Publication". Papers published in the quarter appear under the subheading "Recently Published". Following each abstract is the name and telephone number of the individual to contact for more information on the topic (usually the first author). This issue also includes a calendar of Center conferences and workshops planned for calendar year 1987 and a list of sponsors of the work.

Center for Electronics and Electrical Engineering: Center programs provide national reference standards, measurement methods, supporting theory and data, and traceability to national standards.

The metrological products of these programs aid economic growth by promoting equity and efficiency in the marketplace, by removing metrological barriers to improved productivity and innovation, by increasing U. S. competitiveness in international markets through facilitation of compliance with international agreements, and by providing technical bases for the development of voluntary standards for domestic and international trade. These metrological products also aid in the development of rational regulatory policy and promote efficient functioning of technical programs of the Government.

The work of the Center is divided into two major programs: the Semiconductor Technology Program, carried out by the Semiconductor Electronics Division in Gaithersburg, MD, and the Signals and Systems Metrology Program, carried out by the Electrosystems Division in Gaithersburg and the Electromagnetic Fields and Electromagnetic Technology Divisions in Boulder, CO. Key contacts in the Center are given on the back cover; readers are encouraged to contact any of these individuals for further information. To request a subscription or for more information on the Bulletin, write to CEEE Technical Progress Bulletin, National Bureau of Standards, Metrology Building, Room B-358, Gaithersburg, MD 20899 or call (301) 975-2220.

Center sponsors: The Center Programs are sponsored by the National Bureau of Standards and a number of other organizations, in both the Federal and private sectors; these are identified on page 25.

Note on Publication Lists: Guides to earlier as well as recent work are the publication lists covering the work of each division. These lists are revised and reissued on an approximately annual basis and are available from the originating division. The current set is identified in the Additional Information section, page 22.

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SEMICONDUCTOR TECHNOLOGY

Silicon Materials

Released for Publication

Bennett, H.S., **Indirect Energy Gap of Si, Doping Dependence.**

The doping dependence of the indirect energy gap of silicon is reviewed for the Electronic Materials Information Service of IEE (London). This review is a guide with commentary to assist readers in selecting which values are best for their applications. Our state of knowledge in this area is such that in many cases the intended application for the data on bandgap changes determines the appropriate values to use. Data from interpreting both electrical and optical measurements are given.
[Contact: Herbert S. Bennett, (301) 975-2079]

Carver, G.P., Kang, S.S., Ehrstein, J.R., and Novotny, D.B., **Well-Defined Contacts Produce Accurate Spreading Resistance Measurements.**

Values of silicon resistivity calculated from spreading resistance measurements agree with values of resistivity determined from four-point probe measurements over a range of dopant density from 9×10^{14} to 2×10^{17} cm^{-3}. The spreading resistance resistivity values were determined solely using a mathematical expression based upon a simple geometrical model, without the need for a separate calibration. The measurements were made using aluminum-silicon contacts having a well-defined geometry. Arrays of such contacts were also used to characterize local resistivity variations. Two-contact spreading resistance measurements are shown to underestimate the amplitude of resistivity variations compared to one-contact measurements.
[Contact: Gary P. Carver, (301) 975-2091]

Dimensional Metrology

Released for Publication

Larrabee, R.D., **Submicrometer Optical and SEM Linewidth Metrology**, to be published in the Proceedings of the 1987 Measurement Science Conference, Irvine, California, January 29-30, 1987.

The feature sizes on modern integrated circuits are presently taxing the ability of visible-light optical systems to perform the necessary dimensional measurements required during their production. With the shrinking of feature dimensions to the micrometer and submicrometer level, diffraction and finite wavelength become the limitations of existing optical systems. In an effort to overcome these limitations, metrology systems based on the scanning electron microscope (SEM) have appeared and are often assumed to be the panacea of all the problems and the limitations of existing optical systems. In response to the application of the SEM to these problems, new optical systems have appeared including ultraviolet and laser scanning systems. This paper takes a critical look at the basic optical and SEM metrologies, outlines the program at the National Bureau of Standards to provide micrometer and submicrometer feature-size standards for both technologies, and discusses what can be done in practice until suitable standards become available.
[Contact: Robert D. Larrabee, (301) 975-2298]

Nyyssonen, D., **Metrology In Microlithography**, to be published as a book chapter in VLSI Electronics Microstructure Science, Microlithography for VLSI, N.G. Einspruch, ed. (Academic Press).

The advent of very-large-scale and very-high-speed integrated-circuit technologies has had enormous impact on the requirements for accuracy and precision of dimensional metrology. Accurate and precise measurements are needed to improve yield, to ensure that lithographic and critical dimension measurement systems meet specifications, to establish

Dimensional Metrology, cont'd.

control of fabrication processes, and to relate measurements to theory or to serve as input data to modeling or simulation programs. The push to micrometer and submicrometer feature sizes on larger and larger wafers requires dimensional measurement systems with precision and accuracy which can take up only a small fraction of the error budget of 10% or less allowed in process control. By the gauge maker's rule, the measurement system tolerance must be three to ten times less than the tolerance on the part being manufactured. This book chapter discusses some of the unique requirements which metrology places on optical and scanning electron microscope measurement systems and provides a framework for realistically evaluating the capabilities of a given dimensional-measuring system in the context of the purpose for which the measurement system is to be used.
[Contact: Robert D. Larrabee, (301) 975-2298]

Nyyssonen, D., **A Practical Method for Edge Detection and Focusing for Linewidth Measurements on Wafers**, to be published in Optical Engineering.

Lack of precision and accuracy of in-process critical dimension (CD) measurements of linewidth continues to be a serious problem at micrometer and submicrometer dimensions. Even with highly repeatable optical linewidth measurement systems, variable "offsets" or errors have been shown to occur with changes in process variables such as thickness of the patterned layer and sublayers and changes in the indices of refraction of the materials. All of these variations result in a change in the optical phase difference that occurs on reflection at the line edge and, therefore, result in changes in the structure of the optical image. Although an accurate coherent optical edge-detection method has been developed, it requires accurate knowledge of this phase difference, which is not always possible in CD measurements. This paper proposes a new dual-threshold method for edge detection and focusing, based on image theory, which can be adapted to most optical microscope based measurement systems. It does not require knowledge of the phase discontinuity at the line edge. The accuracy of this criterion is compared to two more widely used criteria, 1) the minimum and 2) 50% threshold, and it is concluded that, when the phase difference is unknown and varies with normal processing, the new dual-threshold method is the superior method.
[Contact: Robert D. Larrabee, (301) 975-2298]

Nyyssonen, D., and Kirk, C., **Modeling of the Optical Microscope Imaging of Lines Patterned in Thick Layers with Variable Edge Geometry.**

A monochromatic, waveguide model is presented which can predict the optical microscope images of line objects with arbitrary edge geometry, patterned in thick layers, including multilayer structures with sloping, curved, and undercut edges, granular structures such as lines patterned in polysilicon, as well as asymmetric objects. The model is used to illustrate the effects of line edge structure on the optical image. Qualitative agreement with experimentally obtained optical image profiles is demonstrated. Application of the model to study the effects of variations in layer thickness and edge geometry on linewidth measurements made at different stages of manufacturing integrated circuit devices is discussed.
[Contact: Robert D. Larrabee, (301) 975-2298]

Nyyssonen, D., and Larrabee, R.D., **Submicrometer Metrology in the Optical Microscope**, to be published in the NBS Journal of Research.

The recent impetus of the semiconductor industry toward submicron feature sizes on integrated circuits has generated an immediate need for measurement tools and

Dimensional Metrology, cont'd.

standards suitable for these features. Optical techniques have the advantages of being nondestructive and of having high throughput, but the disadvantage of using wavelengths comparable to feature size which results in complex scattered fields and image structures that are difficult to interpret. Although submicron optical linewidth measurement is possible for 0.3-μm feature sizes, current instrumentation and linewidth standards, particularly for wafers, will have to improve radically in accuracy, as well as in precision, to meet the anticipated needs of the IC industry for submicron dimensional metrology. This paper discusses the effects of inadequate precision and accuracy on process control in IC fabrication and suggests some ways of circumventing these limitations until better instrumentation and standards become available.
[Contact: Robert D. Larrabee, (301) 975-2298]

Postek, M.T., **Non-Destructive Submicron Dimensional Metrology Using the Scanning Electron Microscope**, to be published in Review of Progress in NDE.

The increasing evolution of microelectronics into the submicron region necessitates non-destructive examination of these structures both for linewidth measurement and defect inspection by systems other than the optical microscope. The scanning electron microscope operated in the low beam-voltage mode has been recently employed in this work due to its potentially high spatial resolution and depth of field. This paper discusses realistic applications of the scanning electron microscope to non-destructive microelectronics inspection and metrology in light of the present instrument specifications and capabilities and relates them to the processing controls required for submicron metrology.
[Contact: Michael T. Postek, (301) 975-2299]

Recently Published

Postek, M.T., and Joy, D.C., **Microelectronics Dimensional Metrology in the Scanning Electron Microscope, Part I**, Solid State Technology, Vol. 29, No. 11, pp. 145-150 (November 1986); **Part II**, Solid State Technology, Vol. 29, No. 12, pp. 77-85 (December 1986) [also to appear in NBS Journal of Research].

The increasing integration of microelectronics into the submicrometer region for very-large-scale and very-high-speed integrated-circuit applications necessitates the examination of these structures both for linewidth measurement and for defect inspection by systems other than the optical microscope. The low beam-voltage scanning electron microscope (SEM) has been employed recently in this work due to its potentially high spatial resolution and to its large depth of field. The applications of the scanning electron microscope to microelectronics inspection and metrology are discussed in light of the present instrument specifications and capabilities, and the processing controls required for submicrometer processing are examined. The discussion includes effects of the electron beam/sample interaction and its modeling with the Monte Carlo technique. Various sources of error in SEM metrology are also examined. In conclusion, the prospect of automated wafer inspection and progress in establishing SEM measurement standards are outlined.
[Contact: Michael T. Postek, (301) 975-2299]

Packaging

Recently Published

Oettinger, F.F., **Thermal Characterization of Integrated Circuits -- A Tutorial**, Proceedings of Semiconductor Thermal and Temperature Measurement Symposium, Scottsdale, Arizona, December 9-11, 1986, pp. T2-1 to T2-4 (1986).

Packaging, cont'd.

This tutorial deals with the practicalities of the thermal characterization of integrated circuit devices and packages, utilizing both computational and experimental techniques.
[Contact: Frank F. Oettinger, (301) 975-2054]

Integrated Circuit Test Structures

Released for Publication

Schafft, H.A., **Thermal Analysis of Electromigration Test Structures**, to be published in IEEE Transactions on Electron Devices (special issue on Interconnections and Contacts for VLSI).

A thermal analysis of a straight-line resistor test structure is used to show how test structure design and test conditions can affect the accuracy of electromigration characterizations of metallizations. Recommendations for the design and use of electromigration test structures are given.
[Contact: Harry A. Schafft, (301) 975-2234]

Schafft, H.A., Staton, T., Mandel, J., and Shott, J., **Reproducibility of Electromigration Measurements**, to be published in the IEEE Transactions on Electron Devices (special issue on Interconnections and Contacts for VLSI).

The reproducibility of median-time-to-failure (t_{50}) measurements was determined in an interlaboratory experiment in which 11 laboratories and a reference laboratory took part. Each laboratory used a method of its choosing to test equivalent samples under the same conditions of current density and oven temperature. The between-laboratory reproducibility of t_{50} measurements normalized to one metallization temperature was dependent on current-density stress: at 1.0 MA/cm^2 it was within 15%, while at 2.5 MA/cm^2 it was generally within 50%. The primary source for variability is in estimating the temperature rise of the test metallization due to joule heating. Recommendations are given for the design and test of electromigration test structures to improve the reproducibility of t_{50} measurements.
[Contact: Harry A. Schafft, (301) 975-2234]

Device Physics and Modeling

Released for Publication

Bennett, H.S., **Fundamental Principles for Gallium Arsenide Devices**, to be published in the Proceedings of the International Symposium on Circuits and Systems, Philadelphia, Pennsylvania, May 4-7, 1987.

Recent advances in physics for submicron silicon devices suggest lessons or principles that are valid when numerically simulating the behavior of GaAs devices. These lessons from physics for silicon devices are summarized and their implications for GaAs devices are given.
[Contact: Herbert S. Bennett, (301) 975-2079]

Bennett, H.S., **Indirect Energy Gap of Si, Doping Dependence.**

The doping dependence of the indirect energy gap of silicon is reviewed for the Electronic Materials Information Service of IEE (London). This review is a guide with commentary to assist readers in selecting which values are best for their applications. Our state of knowledge in this area is such that in many cases the intended application for the data on bandgap changes determines the appropriate values to use. Data from interpreting both electrical and optical measurements are given.
[Contact: Herbert S. Bennett, (301) 975-2079]

Bennett, H.S., and Lowney, J.R., **Models for Heavy Doping Effects in Gallium Arsenide.**

Device Physics and Modeling, cont'd.

Knowledge of the parameters that describe how the band edges, densities of states, and the effective intrinsic carrier concentrations vary with dopant and carrier densities is essential for reliable predictions from numerical simulations of GaAs/AlGaAs devices and for interpreting optical measurements. Klauder's self-energy method, which is self-consistent, is used to calculate the effects due to the interactions between carriers and dopant ions in GaAs at 300 K. The many-body effects due to the interactions among the carriers themselves, exchange and correlation, are estimated by evaluating expressions similar to those of Abram et al. at 300 K. When densities exceed about 5×10^{16} cm^{-3} in n-type GaAs and 10^{18} cm^{-3} in p-type GaAs, carrier-dopant ion interactions and carrier-carrier interactions become significant and should be included in calculations of band structure changes and of properties which depend on the density of states such as carrier transport, effective intrinsic carrier concentrations, and coefficients for optical absorption.
[Contact: Herbert S. Bennett, (301) 975-2079]

Bennett, H.S., **Submicron Device Physics for Numerical Simulations.**

Recent advances in physics for submicron, bipolar-crystalline devices suggest principles that are valid when modeling bipolar devices with noncrystalline regions such as those with polysilicon, polycrystalline silicon, and hydrogenated amorphous silicon emitters. These principles from crystalline device physics are summarized, and their implications for the noncrystalline regions of bipolar devices are given.
[Contact: Herbert S. Bennett, (301) 975-2079]

Gaitan, M., and Mayergoyz, I.D., **Time Perturbation Analysis for the MOS System.**

The development of a numerical implementation of the small-signal response of MOS (metal oxide-semiconductor) capacitors, using time perturbation analysis is discussed. The effects of nonconstant doping profiles and interface and bulk traps are included. The model uses Fermi-Dirac statistics to describe the occupancy of the interface and bulk traps. The oxide region is considered to have no mobile carriers and any fixed oxide charge distribution is modeled as a charge sheet at the $Si-SiO_2$ interface. This technique can be used to find the small signal response of a device from the static solution.
[Contact: Michael Gaitan, (301) 975-2070]

Recently Published

Bennett, H.S., **High Dopant and Carrier Concentration Effects in Gallium Arsenide: Band Structure & Effective Intrinsic Carrier Concentrations,** Journal of Applied Physics, Vol. 60, No. 8, pp. 2866-2874 (15 October 1986).

The quality and reliability of predictions from numerical simulations of GaAs/AlGaAs devices, such as heterojunction bipolar transistors, depend on input parameters. These parameters include the variations with doping and carrier concentrations of the valence and conduction band edges and of the effective intrinsic carrier concentrations for heavily doped p-type and n-type gallium arsenide. The Klauder self-energy method is used to calculate the effects of the one-body interactions among the dopant ions and the carriers in heavily doped gallium arsenide at 300 K. The many-body interactions of exchange and correlation are estimated by interpreting optical absorption measurements and by calculations based on degenerate theory. When densities exceed 10^{19} cm^{-3} in p-type and 10^{17} cm^{-3} in n-type GaAs, one-body and many-body terms become of the same order of magnitude and should be included in calcula-

Device Physics and Modeling, cont'd.

tions of band structure changes and of properties which depend on the density of states, such as carrier transport and effective intrinsic carrier concentrations.
[Contact: Herbert S. Bennett, (301) 975-2079]

Bennett, H.S., **Modeling Silicon Emitters for VLSI Transistors**, Proceedings of the Workshop on New Developments in the Physics of Homojunctions and Heterojunctions, Leuven, Belgium, May 28-29, 1986, unpaged (December 1986).

The accuracy and reliability of predictions from numerical simulations of advanced bipolar transistors for very-large-scale integration (VLSI) applications depend on model parameters. These parameters include the variations with doping and carrier concentrations in both n-type and p-type silicon of 1) the valence and conduction band edges, 2) the effective intrinsic carrier concentrations, 3) the minority carrier mobilities, and 4) the minority carrier lifetimes. This paper reviews recent advances in device physics for modeling the emitters of bipolar transistors with submicrometer dimensions and high concentrations of dopant ions and carriers.
[Contact: Herbert S. Bennett, (301) 975-2079]

Lowney, J.R., **Impurity Bands and Band Tailing in n-Type GaAs**, Journal of Applied Physics, Vol. 60, No. 8, pp. 2854-2859 (15 October 1986).

The densities of states of the valence and conduction bands of n-type GaAs have been calculated for a donor density of 10^{17} cm^{-3} at 300 K and 20 K. Both the donor-carrier and carrier-carrier interactions have been included. Band tails appear on both bands and the energy gap is narrowed. Calculations were also performed for a donor density of 10^{15} cm^{-3}. The results show the formation of an impurity band at 20 K, whereas a band tail exists at 300 K.
[Contact: Jeremiah R. Lowney, (301) 975-2048]

Radiation Effects

Recently Published

Hefner, A.R., Blackburn, D.L., and Galloway, K.F., **The Effect of Neutrons on the Characteristics of the Insulated Gate Bipolar Transistor (IGBT)**, IEEE Transactions on Nuclear Science, Vol. NS-33, No. 6, pp. 1428-1434 (December 1986).

The effects of neutrons on the operating characteristics of Insulated Gate Bipolar Transistors (IGBT) are described. Experimental results are presented for devices that have been irradiated up to a fluence of 10^{13} neutrons/cm^2, and an analytical model is presented which explains the observed effects. It is found that with increasing neutron fluence, the on-state voltage increases, the switching time decreases, and the saturation current decreases. For the range of fluences studied, the observed effects result from a reduction in minority carrier lifetime in the IGBT and not from changes in the effective dopant density. The effects of neutrons on the IGBT are compared with their known effects on power metal oxide-semiconductor field-effect transistors (MOSFETs), and it is shown that the IGBT characteristics begin to degrade at a fluence that is an order of magnitude less than the fluence at which the power MOSFET begins to degrade. At high fluences, the IGBT takes on the characteristics of a power MOSFET.
[Contact: Allen R. Hefner, (301) 975-2071]

Pugh, R.D., Johnston, A.H., and Galloway, K.F., **Characteristics of the Breakdown Voltage of Power MOSFETs After Total Dose Irradiation**, IEEE Transactions on Nuclear Science, Vol. NS-33, No. 6, pp. 1460-1464 (December 1986).

The effects of total dose irradiation on

Radiation Effects, cont'd.

the breakdown voltage of p-channel power metal oxide-semiconductor field-effect transistors (MOSFETs) are examined. Although breakdown voltage for p-channel devices increased at higher dose levels, as expected, some devices exhibited an initial decrease in breakdown at very low levels of total dose. The interaction of ionizing radiation effects with the junction termination methods designed to increase the voltage at which breakdown occurs is analyzed.
[Contact: Thomas J. Russell, (301) 975-2973]

Russell, T.J., Bennett, H.S., Gaitan, M., Suehle, J.S., and Roitman, P., **Correlation Between CMOS Transistor and Capacitor Measurements of Interface Trap Spectra**, IEEE Transactions on Nuclear Science, Vol. NS-33, No. 6, pp. 1228-1233 (December 1986).

The radiation-induced change in the energy spectra of SiO_2-Si interface traps as determined using 1) the charge-pumping and weak-inversion techniques on compound metal oxide-semiconductor (CMOS) transistors and 2) using the quasi-static capacitance voltage and detailed model techniques on CMOS capacitors are compared. The interface trap spectra determined from these measurements are in good quantitative agreement over most of the band gap for the range of densities of traps approximately 10^{10} to 10^{12} cm^{-1} eV^{-1}.
[Contact: Thomas J. Russell, (301) 975-2073]

Singh, G., Galloway, K.F., and Russell, T.J., **Radiation-Induced Interface Traps in Power MOSFETs**, IEEE Transactions on Nuclear Science, Vol. NS-33, No. 6, pp. 1454-1459 (December 1986).

Methods for estimating values of radiation-induced interface trapped charge from the current-voltage (I-V) characteristics of metal oxide-semiconductor field-effect transistors (MOSFETs) are described and applied to commercially available power MOSFETs. The power MOSFETS show severe degradation on radiation exposure with the effects of positive oxide trapped charge dominating; however, interface trap buildup is significant. The results are compared to experimental measurements available on other technologies.
[Contact: Thomas J. Russell, (301) 975-2073]

Insulators and Interfaces

Released for Publication

Mountain, D.J., Galloway, K.F., and Russell, T.J., **The Effect of Post-Oxidation Anneal on the Electrical Characteristics of Thin Oxides.**

In this study, the effects of pre- and post-oxidation treatments on thin (~20-nm) gate oxide properties have been made. Pre-oxidation cleans and post-oxidation anneal (POA) times and ambients were compared. Flatband voltage, oxide field breakdown, and average density of interface trap measurements were used to evaluate the different sequences. The data indicate that an optimum oxidation sequence for thin gate oxides can be designed. A sacrificial oxidation cleaning procedure and a long (120-min) POA in nitrogen gave the oxide with the best electrical characteristics.
[Contact: Thomas J. Russell, (301) 975-2073]

Other Semiconductor Topics

Recently Published

Larrabee, R.D., and Bell, M.I., **Nondestructive Evaluation Activities in the Semiconductor Materials and Processes Division**, NBSIR 86-3495 (December 1986).

This is the first of an anticipated yearly report of the nondestructive evaluation and measurement development activities currently in progress in the Semiconductor Materials and Processes

Other Semiconductor Topics, cont'd.

Division of the National Bureau of Standards. Present activities include production and certification of standard reference materials for resistivity and optical measurement of linewidths on transparent photomasks; orchestrating round robins for ellipsometric layer thickness, deep-level characterization, and spreading resistance; developing new techniques for optical deep-level spectroscopy, profiling resistivity, and recombination lifetime in ingots of very high resistivity silicon; for measuring oxygen in silicon by infrared absorption; for characterizing compound semiconductor wafers by optical and x-ray techniques; and for extending the photomask linewidth work to thicker lines on silicon substrates.
[Contact: Robert D. Larrabee, (301) 975-2298]

Novotny, D.B., **Measurement of the Separation Distance in Contact and Proximity Lithography**, Journal of the Electrochemical Society, Vol. 133, pp. 2600-2605 (December 1986).

A method is presented for measuring the separation distance between the substrate surface and the mask surface in contact and proximity optical lithography. This method utilizes the analysis of the Fresnel diffraction pattern produced by a slit aperture in the mask and physically replicated in the photoresist. From the analysis, the image distance producing the observed Fresnel diffraction pattern is obtained and is used to calculate the separation distance. The conditions for the application of this method are presented and an easy method for computer-generation of the Fresnel diffraction patterns is described. A simplified method for estimating the separation distance from the number of diffraction pattern peaks and valleys is also given. Results are presented showing that a finite separation distance may exist in hard "contact" lithography and that this measurement method is applicable from distances from near zero to 20 or more micrometers.
[Contact: Donald B. Novotny, (301) 975-2699]

Stern, E.A., Ma, Y. and Bouldin, C.E. **Answer to Comment by M.A. Marcus Concerning "Local Structure at Mn Sites in Icosahedral Mn-Al Quasicrystals"**, Physical Review Letters, Vol. 57, No. 13, p. 1659 (September 29, 1986).

A response is given to M.A. Marcus who raised questions about the data analysis leading to conclusions that EXAFS data of Stern et al. support a model involving two Mn sites, one of which is like that in α-Al_6Mn. The response showed that the results are consistent with the data and analysis presented in the paper.
[Contact: Charles E. Bouldin, (301) 975-2046]

Wunder, S.L., Bell, M.I., and Zerbi, G., **Band Broadening of CH_2 Vibrations in the Raman Spectra of Polymethylene Chains**, Journal of Chemical Physics, Vol. 85, No. 7, pp. 3827-3839 (1 October 1986).

The isotropic and anisotropic linewidths of methylene vibrations in a homologous series of alkanes of increasing chain length have been measured in the liquid state as a function of temperature. The bandwidths of the CH_2 symmetric stretching modes, which are in Fermi resonance with overtones of the CH_2 bending vibrations, are temperature insensitive over a 200-K interval, explained in terms of a vibrational dephasing mechanism (inhomogeneous broadening) for these modes. In contrast, for the bending and antisymmetric vibrations, significant band broadening occurs over this same temperature interval. In addition, for these modes, both the absolute value of the bandwidth and the relative rate of increase of the bandwidth with increasing temperature decrease with increasing chain length. These observations are consistent with a reorientational broadening mechanism as

Other Semiconductor Topics, cont'd.

the principal bandwidth contribution for these vibrations. Hindered end-over-end rotation of the molecules, which contributes to the band broadening for very low molecular weight alkanes, rapidly becomes too slow to be observable on the time scale of the Raman experiment for the higher molecular weight alkanes and polyethylene. For longer chain lengths, torsional backbone motions coupled to the high frequency antisymmetric stretching modes can account for the breadth of the bands.
[Contact: Michael I. Bell, (301) 975-2081]

FAST SIGNAL ACQUISITION, PROCESSING, AND TRANSMISSION

Waveform Metrology

Released for Publication

Schoenwetter, H.K., Flach, D.R., Souders, T.M., and Bell, B.A., **A Precision Programmable Step Generator for Use in Automated Test Systems**, to be published as NBS Technical Note 1230.

A precision voltage step generator has been designed for use in automated systems to test the dynamic response of waveform recorders and other instruments. The programmable pulse parameters include transition polarity, pulse length, and repetition rate. The initial and final levels of voltage steps are each programmable within the range of ±1 V for a 50-Ω termination and within ±5 V for a high impedance load. Voltage steps within these ranges settle to within ±0.02% of full scale range in less than 22 and 26 ns, respectively, for small load capacitance. The corresponding transition durations are approximately 6 and 7 ns.
[Contact: Howard K. Schoenwetter, (301) 975-2414]

Turgel, R.S., and Vecchia, D.F., **Precision Calibration of Phase Meters**, to be published in the IMTC/87 Conference Record of the IEEE Instrumentation/Measurement Technology Conference, Boston, Massachusetts, April 27-29, 1987.

A procedure and statistical analysis for the calibration of precision phase meters has been developed. The method can be applied equally to the calibration of any instrument that has a nominally linear response characteristic. Using statistical tests, the method checks whether the calibration data fits a linear model and then determines the linear equation from which the corrected calibration values are computed. Because random fluctuations tend to mask the limiting mean of the instrument response, the corrections are based on the values computed from the calibration curve, rather than on the actual calibration data.

To obtain the data, test points are chosen to cover the range to be calibrated, and several sets of calibration readings are taken by comparing the instrument under test to a standard. The replication of the data at the selected test points serves to characterize the repeatability and to decide whether the linear model is appropriate. If the assumption of a linear model is correct, the data are fitted to a straight line (calibration curve), and statistical tests are used to determine if the slope and intercept of the calibration curve are significantly different from their ideal values.

As a next step, the error limits of the readings from the instrument under test are computed for three conditions: no corrections applied, only a constant correction applied, and the full calibration curve used for the corrections. The three error limits are then compared to the instrument specifications to determine which type of calibration correction, if any, is needed.
[Contact: Raymond S. Turgel, (301) 975-2420]

Waveform Metrology, cont'd.

Recently Published

Kanada, T., and Franzen, D.L., **Optical Waveform Measurement by Optical Sampling with a Mode-Locked Laser Diode,** Optics Letters, Vol. 11, No. 1, pp. 4-6 (January 1986).

Optical pulses from a GaAlAs laser diode directly modulated at a frequency f_0 (971 MHz) are mixed in a $LiIO_3$ crystal with optical sampling pulses at a frequency of f_0 - 10 Hz from a mode-locked GaAlAs laser diode. The optical signal obtained by sum-frequency mixing in the crystal is observed with a photomultiplier and an oscilloscope. The original pulse waveform is reproduced clearly with a temporal resolution equal to the mode-locked laser-diode pulse width and at a repetition frequency of 10 Hz. Similar results are obtained with InGaAsP laser diodes at a wavelength of 1.3 μm.
[Contact: Douglas L. Franzen, (303) 497-3346 or -5342]

Cryoelectronic Metrology

Released for Publication

Cirillo, M., and Lloyd, F.L., **Phase Lock of a Long Josephson Junction to an External Microwave Source.**

A long Josephson junction dc biased on a zero-field singularity and emitting radiation at microwave frequencies is irradiated with external microwave power. This power can be supplied either by a room-temperature oscillator or by another long junction. We find that the oscillations of the junction can lock coherently to the external signal for frequency intervals ranging from 500 kHz to 50 MHz. The dependence of the width of these intervals of coherence on the external microwave power is measured for the case in which the power is generated by a room-temperature oscillator.
[Contact: Frances L. Lloyd, (303) 497-3254 or 3988]

Hamilton, C.A., Kautz, R.L., Lloyd, F.L., Steiner, R.L., and Field, B.F., **The NBS Josephson Array Voltage Standard.**

A Josephson voltage standard based on a series array of 2076 junctions is described. With a 15-mW input at 96 GHz, the array produces 15,000 quantized levels between -1.5 and 1.5 V. Initial results on high-precision comparisons with a Zener reference standard are given.
[Contact: Clark A. Hamilton, (303) 497-3740 or -3988]

Kautz, R.L., **Global Stability of the Chaotic State Near an Interior Crisis,** to be published in the Proceedings of the Workshop on Structure, Coherence, and Chaos in Dynamical Systems, Copenhagen, Denmark, July 12-16, 1986.

In dissipative systems, chaotic trajectories are locally unstable in that they show a sensitive dependence on initial conditions, but globally stable in that they are represented by attractors. Using the radio-frequency-biased Josephson junction as an example, global stability of the chaotic state is explored in the neighborhood of an interior crisis. A measure of global stability is developed by considering the response of the system to thermal noise. In the presence of noise, the system occasionally escapes from the region of state space containing the attractor, and the temperature dependence of the average escape time is characterized by an activation energy. This activation energy is a useful measure of the global stability of the chaotic state, being analogous to the barrier height for a particle in a potential well.
[Contact: Richard L. Kautz, (303) 497-3391 or -3988]

Kautz, R.L., Hamilton, C.A., and Lloyd, F.L., **Series-Array Josephson Voltage Standards.**

Series arrays typically including 1500 Josephson junctions driven at 90 GHz

Cryoelectronic Metrology, cont'd.

have been used to generate quantized reference voltages in excess of 1 V. Such standards simplify the procedure and reduce the measurement uncertainties in the calibration of electrochemical cells.
[Contact: Richard L. Kautz, (303) 497-3391 or -3988]

McDonald, D.G., **Novel Superconducting Thermometer for Bolometric Applications.**

The temperature dependence of the magnetic penetration depth in a superconductor is proposed as a basis for a sensitive thermometer. This depth is monitored through the inductance of a microstrip transmission line, which is incorporated into an impedance measuring bridge. The bridge is envisioned as an integrated circuit with all critical components at low temperature. It is estimated that the contribution to the noise equivalent power by the sum of the Josephson noise and the preamplifier noise can be reduced to about 7×10^{-20} watt per root hertz, which is approximately four orders of magnitude below currently realized values. Performance of this device as a bolometer is limited by noise from the thermal conductance of the bolometer mount with the present state of the art.
[Contact: Donald G. McDonald, (303) 497-5113]

Ono, R.H., Cromar, M.W., Kautz, R.L., Soulen, R.J., Colwell, J.H., and Fogle, W.E., **Current-Voltage Characteristics of Nanoampere Josephson Junctions**, to be published in the Proceedings of the 1986 Applied Superconductivity Conference, Baltimore, Maryland, September 28-October 3, 1986. [To appear in IEEE Transactions on Magnetics, March 1987]

We have studied the current-voltage (I-V) characteristics of small-area tunnel junctions at temperatures below 1 K. The junctions were made in an edge geometry with an Nb base electrode and had areas less than 0.05 μm^2 and critical currents in the nanoampere range. Although the measured I-V characteristics resemble those of ordinary hysteretic junctions, the supposed zero-voltage portion of the curve proved to have a finite slope and to deviate from zero voltage. For these junctions, it is apparently possible for occasional 2π phase slips to occur without switching to the usual voltage state. This behavior can be explained either by macroscopic quantum tunneling or by a model in which the effective shunt conductance of the junction is frequency-dependent.
[Contact: Michael W. Cromar, (303) 497-5375]

Recently Published

McDonald, D.G., **Modeling a Voltage-Locked Josephson Junction Array Amplifier: Gain, Input Impedance, and Bandwidth,** Journal of Applied Physics, Vol. 60, No. 9, pp. 3247-3257 (November 1, 1986).

Previously published experimental results are used to deduce an equivalent circuit for this amplifier, based on the shunted junction model. It is found that the very small inductances of the junction shunt resistors play an important role in determining the shape of the current-voltage curves in the voltage-locked region. Once the circuit is determined using the shunted junction model, a combination of an approximation method (the method of slowing varying amplitudes) and the shunted junction model is used to approximately maximize the power gain of the circuit. The maximum gain achieved in these simulations of the two-junction amplifier is 11.3. This gain occurred with a negative resistance input impedance of $-0.41R$ and a signal source impedance of $0.167R$, where R is the junction shunt resistance. It is estimated that the bandwidth of this amplifier is about 1 GHz.
[Contact: Donald G. McDonald, (303) 497-5113]

Antenna Metrology

Released for Publication

Francis, M.H., and Newell, A.C., **Multiple Reflection Effects On a Near-Field Range**, to be published in the Proceedings of the Antenna Measurement Techniques Association Conference, Ottawa, Canada, September 23-25, 1986.

For many years it has been recognized that multiple reflections between the probe and antenna under test are a source of error in near-field measurements. For planar measurements, corrections can be made by using the rather cumbersome technique of obtaining data over many planes and averaging the results. NBS has developed a test for estimating the magnitude and character of the effects upon the far field due to multiple reflections occurring between the antenna under test and the probe. The procedure uses one-dimensional near-field scans measured at multiple separation distances. For each separation distance, the one-dimensional far field is obtained using a Fourier transform. The resulting far fields are then averaged in a complex manner. The difference between the average far field and each of the other far fields is primarily due to multiple reflections.
[Contact: Michael H. Francis, (303) 497-5873]

Hill, D.A., **Far-Field Transient Response of an Antenna from Near-Field Data.**

A theoretical basis for calculating the transient far-field response of an antenna from planar near-field data in either the time domain or the frequency domain has been developed. A double integral must be evaluated if we begin with time-domain data, but a triple integral must be evaluated if we begin with frequency-domain data. However, the frequency-domain integrals are in a form that is suitable for three-dimensional fast Fourier transform. Two idealized examples are studied, and identical results are obtained starting with frequency-domain or time-domain data. The main practical difficulty in determining the transient response is the large number of near-field samples that are required. If data are taken at only a few near-field points, then the singularity expansion method presents a possible method of determining the complex resonances of the antenna under test.
[Contact: David A. Hill, (303) 497-3472]

Hill, D.A., and Francis, M.H., **Out-of-Band Response of Antenna Arrays.**

The response of antenna arrays to out-of-band frequencies has been analyzed using the effective aperture approach. An average value of effective aperture can be obtained by averaging the incidence angle and the polarization of the incident field. Far-field patterns have also been calculated by treating the array element excitations as random variables. The randomness in the element excitations causes a decrease in directivity and an increase in sidelobe level.
[Contact: David A. Hill, (303) 497-3472]

Muth, L.A., **Displacement Errors in Antenna Near-Field Measurements and Their Effect on the Far Field**, to be published as NBS Technical Note 1306.

The effects of probe displacement errors in the near-field measurement procedure on the far-field spectrum are studied. Expressions are derived for the displacement error functions that maximize the fractional error in the spectrum both for the on-axis and off-axis directions. Planar x-y and z-displacement errors are studied first, and the results generalized to position errors in cylindrical and spherical scanning. Near-field models are used to obtain order-of-magnitude estimates for the fractional error as a function of relevant scale lengths of the near field, defined as the lengths over which

Antenna Metrology, cont'd.

significant variations occur.
[Contact: Lorant A. Muth, (303) 497-3603]

Laser Metrology

Released for Publication

Bennett, H.E., Guenther, A.H., Milam, D., and Newnam, B.E., **Laser Induced Damage in Optical Materials: 1984**, to be published as NBS Special Publication 727.

The Sixteenth Annual Symposium on Optical Materials for High Power Lasers (Boulder Damage Symposium) was held at the National Bureau of Standards in Boulder, Colorado, October 15-17, 1984. The Symposium was held under the auspices of ASTM Committee F-1, Subcommittee on Laser Standards, with the joint sponsorship of NBS, the Defense Advanced Research Projects Agency, the Department of Energy, the Office of Naval Research, and the Air Force Office of Scientific Research. Approximately 200 scientists attended the Symposium, including representatives of the United Kingdom, France, West Germany, and the Netherlands. The Symposium was divided into sessions concerning Materials and Measurements, Mirrors and Surfaces, Thin Films, and Fundamental Mechanisms. As in previous years, the emphasis of the papers presented at the Symposium was directed toward new frontiers and new developments. Particular emphasis was given to materials for high power apparatus. The wavelength range of prime interest was from 10.6 μm to the uv region. Highlights included surface characterization, thin-film-substrate boundaries, and advances in fundamental laser-matter threshold interactions and damage mechanisms. Harold E. Bennett of the Naval Weapons Center, Arthur H. Guenther of the Air Force Weapons Laboratory, David Milam of the Lawrence Livermore National Laboratory, and Brian E. Newnam of the Los Alamos National Laboratory were co-chairmen of the Symposium. The Seventeenth Annual Symposium was scheduled for October 28-30, 1985 at the National Bureau of Standards, Boulder.
[Contact: Aaron A. Sanders, (303) 497-5341]

Recently Published

Johnson, E.G., **Direct Measurement of the Spatial Modes of a Laser Pulse - Theory**, Journal of Applied Optics, Vol. 25, No. 17, pp. 2967-2975 (September 1986).

We make an electric-field measuring apparatus by using optical processing, tapered optical fibers, and a pair of detectors at the end of each optical fiber. Using an appropriate computer-generated hologram (CGH), we show it is possible to discriminate among a set of orthonormal modes used to represent the spatial features of the electric field with a signal-to-noise ratio of at least 100 to 1. The tapered fiber is a mode filter that is used in the transform plane of the CGH. This fiber allows precise determination of the strength of each of the orthonormal modes being used as the spatial basis of the electric field before the optical processing.
[Contact: Eric G. Johnson, (303) 497-3234]

Microwave and Millimeter-Wave Metrology

Released for Publication

Adair, R., Reeve, G., and Gatterer, L.E., **The Expanding Need for Microwave and Millimeter Wave Calibration Services.**

Several technology surveys concerning millimeter-wave measurement needs and capabilities have been conducted by the National Bureau of Standards Boulder Laboratories and others. The results of some of these studies are summarized. Current microwave- and millimeter-wave standards and calibration capabilities at the National Bureau of Standards are reviewed. The lack of national stan-

Microwave & Millimeter-Wave, cont'd.

dards in certain frequency bands may lead to problems with the specification, acceptance testing, calibration, and critical use of some components and systems.
[Contact: Gerome R. Reeve, (303) 497-3557]

Clague, F.R., and Larsen, N.T., **A Transient Response Error in Microwave Power Meters Using Thermistor Detectors.**

Broadband coaxial thermistor mounts are commonly used in automated precision microwave measurement systems such as six-port networks. To reduce the effect of temperature drift and to decrease the total measurement time, it is desirable to measure the thermistor mount dc bias voltage very quickly after turning the radio frequency on or off. However, investigation has revealed that a coaxial mount may take much longer to settle to a stable dc bias voltage than the thermistor element time constant or the associated power meter servo bandwidth would indicate. If the bias voltage is measured before this transient ends, the error in the calculated radio-frequency power can be very large; as much as 1.4% has been observed. This paper describes these transients and gives measured durations and maximum error for a number of different bolometer mounts.
[Contact: Fred B. Clague, (303) 497-5778]

McDonald, D.G., **Novel Superconducting Thermometer for Bolometric Applications.**

The temperature dependence of the magnetic penetration depth in a superconductor is proposed as a basis for a sensitive thermometer. This depth is monitored through the inductance of a microstrip transmission line, which is incorporated into an impedance measuring bridge. The bridge is envisioned as an integrated circuit with all critical components at low temperature. It is estimated that the contribution to the noise equivalent power by the sum of the Josephson noise and the preamplifier noise can be reduced to about 7×10^{-20} watt per root hertz, which is approximately four orders of magnitude below currently realized values. Performance of this device as a bolometer is limited by noise from the thermal conductance of the bolometer mount with the present state of the art.
[Contact: Donald G. McDonald, (303) 497-5113]

Recently Published

Hoer, C.A., **On-Line Accuracy Assessment for the Dual Six-Port ANA: Treatment of Systematic Errors,** CPEM (Conference in Precision Electrical Measurements) Digest, NBS Gaithersburg, MD, June 23-27, 1986, R.F. Dziuba, ed., pp. 238-239 [abbreviated version]; [complete paper to be published in a special issue of IEEE Transactions on Instrumentation and Measurement].

Expressions are derived for calculating systematic errors in dual six-port or four-port measurements of reflection coefficient and scattering parameters due to imperfections in the transmission line standard used to calibrate the system. A new mathematical model for a four-port reflectometer makes it easier to visualize and analyze these errors.
[Contact: Cletus A. Hoer, (303) 497-3703]

Optical Fiber Metrology

Released for Publication

Gallawa, R.L., and Li, X., **On the Calibration of Optical Fiber Power Meters: The Effect of Connectors.**

With the proliferation of optical fiber communications systems, there has emerged a pressing need for accurate measurement of optical power at the wavelengths and power levels of interest to the telecommunications community. The most immediate need involves the use

Optical Fiber Metrology, cont'd.

of power meters in a field environment. Thus, connectors and adapters are used in making the measurement. A commercially available power meter, of which there are many brands and types, is the generic building block for field measurements. The calibration of the meter without a connector presents several problems, some of which are alluded to in the paper. When connectors are used, as is often the case, a new set of problems is added to an already complicated set. Fiber connectors and the associated connector adapters, which mate the connectorized fiber to the meter, are of particular interest; these problems are addressed in this paper.
[Contact: Robert L. Gallawa, (303) 497-3761]

Kanda, T., and Franzen, D.L., **Single-Mode Fiber Dispersion Measurements Using Optical Sampling with a Mode-Locked Laser Diode**, Optical Letters, Vol. 11, pp. 330-332 (May 1986).

Pulses from a wavelength-tunable, mode-locked laser diode were measured after 21 km of single-mode fiber propagation by optical sampling with another mode-locked laser diode; a resolution of 0.1 ps/(nm•km) is achieved in this chromatic dispersion measurement. In another related experiment, 78-ps-duration pulses from an ordinary, multilongitudinal-mode laser diode are clearly displayed by optical sampling after 36 km of fiber propagation. System bandwidth increases to approximately 500 GHz km as the laser-diode wavelength is temperature tuned through the zero-dispersion region.
[Contact: Douglas L. Franzen, (303) 497-3346 or -5342]

Yang, S., and Gallawa, R.L., **Fiber Bandwidth Measurement Using Pulse Spectrum Analysis**, Applied Optics, Vol. 25, No. 7, pp. 1069-1071 (April 1986).

The pulse spectrum analysis method (PSA) of measuring fiber bandwidth has been suggested as an alternative to the frequency- and time-domain methods, but there is a paucity of information on the technique and very little data. In fact, we know of no prior measurement comparisons between the PSA method and frequency- and time-domain methods. This paper gives results of an experiment which compared the three methods. The PSA method has the advantage of being very simple and gives results that are consistent with the other two methods. The International Electrotechnical Commission recommends the PSA method, but the Electronics Industries Association of the U.S.A. takes no position in this regard.
[Contact: Robert L. Gallawa, (303) 497-3761)]

Electro-Optic Metrology

Released for Publication

Polak-Dingels, P., Burdge, G., Lee, Chi H., Seabaugh, A.C., Brundage, R.T., Bell, M.I., and Albers, J., **An Investigation of Photoconductive Picosecond Microstripline Switches on Self-Implanted Silicon on Sapphire (SOS)**, to be published in the Conference Proceedings of the 2d Topical Meeting on Picosecond Electronics and Optoelectronics, Incline Village, Nevada, January 14-16, 1987.

Silicon-on-sapphire (SOS) switches, damaged by implantation with 270 keV Si ions at fluence levels of 10^{12} to 2×10^{15} cm^{-2}, have been characterized by picosecond cross-correlation, Raman, and resistivity measurements. Response times as short as 9 ps were measured for an implant dose of 10^{14}. Raman measurements indicate amorphous silicon is not formed until the dose reaches 2×10^{15} cm^{-2}, but there is no further decrease in response time at the higher doses. The resistivity peaks at the same dose level at which the minimum response time is observed, and then decreases for higher dose. The mobility decreases monotonically with increasing implant

Electro-Optic Metrology, cont'd.

dose. We find the optimum implantation condition is one that produces heavy damage in the material without fully amorphizing the silicon. Amorphization decreases the on/off ratio of the device through reduction of both dark resistance and mobility, without increasing the speed of the device.
[Contact: Richard T. Brundage, (301) 975-2958]

Other Fast Signal Topics

Released for Publication

Cavcey, K.H., **Transmission Loss Through 6061 T-6 Aluminum Using a Pulsed Eddy Current Source.**

One method of nondestructive testing in conductors is that of pulsed eddy currents (PECs). In this method, defects modify the electromagnetic field passing through the conductor, with respect to phase (delay) and attenuation. The conductor itself as a transmission medium also modifies the incident field from the PEC source with respect to phase and attenuation. It is therefore important to determine the intrinsic response and transmission loss for any medium of interest. This paper outlines a study of the frequency and phase response (with time-domain techniques based on the PEC source) for seven different thicknesses of aircraft-grade 6061 T6 aluminum alloy.
[Contact: Kenneth H. Cavcey, (303) 497-3995]

Geist, J., **Photodiode Quantum Efficiency and Spectral Responsivity Self-Calibration**, to be published in the Proceedings of the IEEE Instrumentation and Measurement Technology Conference, Boston, Massachusetts, April 27-29, 1987.

High-quality silicon photodiodes can be used as primary radiometric standards in the visible portion of the radiometric spectrum. The physical basis for their use as standards, and their performance in areas pertinent to their use as standards, is reviewed.
[Contact: Jon Geist, (301) 975-2066]

Perrey, A.G., Bell, B.A., and Treado, M.J., **Evaluation of Electronic Monitoring Devices**, to be published as NBSIR 86-3501.

Electronic Monitoring Devices (EMDs) are used to monitor the presence of individuals within a given area who are responsible to the criminal justice system but not confined to institutions. Several EMDs were tested to measure operational characteristics such as operating frequency, approximate range of operation, component capability, and tamper resistance. Tests were conducted in an open field, wooden residence, high rise metal-building, and in a laboratory environment.
[Contact: Arnold G. Perrey, (301) 975-2782]

ELECTRICAL SYSTEMS

Power Systems Metrology

Recently Published

Mehta, S.P., and Petersons, O., **Calibration of Test Systems for Measuring Poser Losses of Transformers**, IEEE Transactions on Power Delivery, Vol. PWRD-1, No. 4, pp. 215-223 (October 1986).

Two years of development work by ASEA Electric, under the auspices of the Industrial Research Associate Program of the National Bureau of Standards, has resulted in a verifiable method of determining overall accuracy of test systems used in the measurement of transformer losses. This technical achievement is important to the industry because of the present trend towards lower power factors which makes loss measurements exceedingly difficult with desirable test system accuracy that is traceable. The technical details of this work are presented in NBS Technical Note

Power Systems Metrology, cont'd.

1204 (over 100-page document). The intent of this IEEE paper is to present the basic principles embodied in the Technical Note. A calibration system for accuracy verification and alignment of test systems is described. Methodologies and data for evaluating accuracy of test systems are summarized. The details elaborated upon in this paper represent a way to determine the accuracy of the overall test system for measuring transformer losses as well as that of the principal components of such a system.
[Contact: Oskars Petersons, (301) 975-2400]

Van Brunt, R.J., and Sauers, I., **Gas Phase Hydrolysis of SOF_2 and SOF_4,** Journal of Chemical Physics, Vol. 85, No. 8, pp. 4377-4380 (October 15, 1986).

The rates for gas-phase hydrolysis of SOF_2 (thionylfluoride) and SOF_4 (thionyltetrafluoride) have been measured at a temperature of 298 K. The second order rate constant for SOF_2 hydrolysis in SF_6 buffer gas was found to have the value $(1.2 \pm 0.3) \times 10^{-23}$ cm^3/s which agrees with previous estimates of Sauers et al., but is three orders of magnitude lower than the value obtained by Ruegsegger et al. at 340 K. The rate constant for SOF_4 hydrolysis has not previously been measured, and its value in both SF_6 and N_2 buffer gases was found here to be $(1.0 \pm 0.3) \times 10^{-21}$ cm^3/s.
[Contact: Richard J. Van Brunt, (301) 975-2425]

Superconductors

Released for Publication

Goodrich, L.F., Pittman, E.S., and Ekin, J.W., **Studies of NbTi Strands Extracted from Coreless Rutherford Cables.**

The electromechanical properties of NbTi strands extracted from coreless Rutherford cables were studied to clarify the relative effects of strand location and field angle on current degradation that occurs in cables that have been compacted into a keystone shape. Detailed critical-current measurements were made on two samples which were fabricated under controlled conditions. These are prototype cables for high-energy physics applications. Specific factors that are addressed are the nature, location, and amount of degradation. This information is intended to lead to methods for reducing the amount of critical-current degradation in cable manufacture.
[Contact: Loren F. Goodrich, (303) 497-3143]

Dragomirecky, M., Minervini, J.V., Ekin, J.W., Goldfarb, R.B., and Clark, A.F., **Losses in a Nb-Ti Superconductor as Functions of AC Field Amplitude and DC Transport Current,** Proceedings of the 11th International Cryogenic Engineering Conference - ICEC 11, Berlin, West Germany, April 22-25, 1986 (Butterworth & Co. Ltd., Publishers), pp. 746-750.

Hysteretic shielding losses and transport losses were measured in a multifilamentary Nb-Ti superconducting coil as functions of transverse ac field amplitude and dc transport current. The conductor was biased with a dc field. There was significant agreement with the predictions of Minervini's two-dimensional theoretical model.
[Contact: John W. Ekin, (303) 497-5448]

Ekin, J.W., **High-Field Flux Pinning and the Strain Scaling Law,** Proceedings of the International Symposium on Flux Pinning and Electromagnetic Properties in Superconductors, Fukuoka, Japan, November 11-15, 1985, pp. 267-271.

The effects of strain on flux pinning in superconductors are discussed. Significant differences between the strain scaling law, temperature scaling law, and the flux-line-shearing model of

Superconductors, cont'd.

Kramer are demonstrated. The strain scaling law is more general than current flux-pinning models, and as such, it may serve as a guide to future work on flux pinning theory. Flux-pinning measurements at fields up to 24 T have been made on a series of high-quality Nb_3Sn samples with third (and fourth) element additions. The data show that the usual extrapolation procedures for determining the bulk-average upper critical field in Nb_3Sn lead to significant errors when additives such as Ti, Ta, Ga, and Hf are present.
[Contact: John W. Ekin, (303) 497-5448]

Fickett, F.R., and Capobianco, T.E., **Relationships Between Mechanical and Magnetoelectric Properties of Oxygen-Free Copper at 4 K**, Advances in Cryogenic Engineering (Materials), Vol. 32, (Plenum Press, New York, NY, 1986), pp. 421-427.

Commercially pure, oxygen-free copper is the material of choice for nearly all superconductor stabilization. Straining relatively pure copper at 4 K can result in significant increases in the residual resistivity and, thus, a decreased ability of the copper to stabilize the superconductor. In this paper, we quantify the effect of strain on the resistivity and magnetoresistivity of a large number of oxygen-free coppers from various sources and in various tempers. In addition, the low-temperature stress-strain behavior of these materials and its correlation with room temperature data and the residual resistivity ratio prior to straining is discussed. An apparatus developed for mechanical properties testing of relatively small wire samples at low temperature is described.
[Contact: Frederick R. Fickett, (303) 497-3785]

Goldfarb, R.B., and Clark, A.F., **AC Losses in Nb-Ti Measured by Magnetization and Complex Susceptibility**, Advances in Cryogenic Engineering (Materials), Vol. 32 (Plenum Press, New York, NY, 1986), pp. 779-786.

DC magnetization and complex ac susceptibility were measured at 4 K as functions of longitudinal dc field for a multifilamentary Nb-Ti superconductor with no transport current. Minor hysteresis loops were obtained in the dc measurements. The full-penetration field H_p, a function of applied field H, was deduced directly for each minor loop. The values for H_p were fit to the Kim-type equation, $H_p(H) = H_p(0)/(1+H/H_k)$, where $H_p(0)$ and H_k are constants. The minor-hysteresis-loop areas gave losses that were in excellent agreement with Carr's theoretical critical-state equation, $W = (4\mu_0 H_0 H_p/3)(1-H_p/2H_0)$, where H_0 is the maximum applied field for each loop.

An expression was obtained for the ideal reversible differential susceptibility, $\chi_{rev} = \phi_0/8\pi\mu_0(H-H_{c1})\lambda^2$, where ϕ_0 is the flux quantum, H_{c1} is the lower critical field, and λ is the penetration depth. H_{c1} and λ for the sample were deduced from the shape of the major hysteresis loop. Clem's theoretical expressions for the real (χ') and imaginary (χ'') components of ac susceptibility are functions of ac field amplitude h, H_p, and χ_{rev}. The predicted susceptibilities based on these expressions were in good agreement with measured curves of χ' and χ'' as functions of h and H. The measured χ' and χ'' were independent of frequency up to 1 kHz, as expected when bulk hysteresis is the primary loss mechanism.
[Contact: Ronald B. Goldfarb, (303) 497-3650]

Goodrich, L.F., Dube, W.P., Pittman, E.S., and Clark, A.F., **The Effect of Aspect Ratio on Critical Current in Multifilamentary Superconductors**, Advances in Cryogenic Engineering (Materials), Vol. 32 (Plenum Press, New York, NY, 1986), pp. 833-840.

Experimental data and discussion are

Superconductors, cont'd.

presented on the critical current of straight superconductors as a function of the orientation of a perpendicular applied magnetic field. Commercial, multifilamentary NbTi and Nb_3Sn samples were measured in a radial access magnet that allowed an arbitrary angle setting. The change in critical current was measured at different magnetic fields to scale the effect for use in a standard test method. For a NbTi sample, the critical current with the magnetic field parallel to the wider face of the conductor is higher than that with the perpendicular orientation. The effect can be as high as 40% for a NbTi sample with an aspect ratio of 6. The effect in Nb_3Sn is opposite that in NbTi. A discussion of the most likely cause of the effect, which accounts for the difference between NbTi and Nb_3Sn, is given.
[Contact: Loren F. Goodrich, (303) 497-3143]

Magnetic Materials and Measurements

Released for Publication

Capobianco, T.E., and Fickett, F.R., **A Proposed Military Standard for Commercial Eddy Current Probes Based on Performance Characterization.**

The latest results of the work being done on a draft military standard for characterizing commercial eddy current probes are reported. We discuss measurement techniques that have been evaluated for suitability as a characterization test method, such as field mapping and various electrical parameter measurements and the reasons for selecting the method which has been incorporated in the present draft. Our conclusion is that the measurement of impedance change of a probe over a range of frequencies on two metals of different conductivities offers the best indicator of eddy current probe sensitivity and proper operating range.
[Contact: Thomas E. Capobianco, (303) 497-3141]

ELECTROMAGNETIC INTERFERENCE

Radiated Electromagnetic Interference

Released for Publication

Crawford, M.L., and Bean, J.L., **NSWC Reverberating Chamber - A High Power Microwave Exposure Chamber,** to be published in the Proceedings of the Third National High Power Microwave Technical Conference, Albuquerque, New Mexico, Dec. 1-5, 1986. [An expanded version appeared under the title "Electromagnetic Radiation Test Facilities Evaluation of Reverberation Chambers Located at NSWC, Dahlgren, Virginia," NBSIR 86-3051 (June 1986).]

This paper describes measurement procedures and results obtained from evaluating the reverberating chamber facility located at the Naval Surface Weapons Center (NSWC), Dahlgren, Virginia. The facility was developed by the NSWC for use in measuring and analyzing the electromagnetic susceptibility/vulnerability (EMS/V) of weapon systems and the shielding effectiveness of enclosures and shielding materials. A brief description of the facility is given including the instrumentation used for performing the evaluation and calibration of the facility and for its use in performing EMS/V tests. Measurements described include the chamber's: 1) insertion loss of coupling efficiency, 2) tuner(s) effectiveness, and 3) test zone E-field uniformity and absolute amplitude calibration. Advantages and limitation for use of the reverberating chamber method are summarized along with comments on interpreting measurement results and on conclusions derived from these studies.
[Contact: Myron L. Crawford, (303) 497-5497]

FitzGerrell, R.G., **NIJ Standard for Mobile Antennas.** [This document provides the technical basis for a standard to be issued by the National Institute of Justice, U.S. Department of Justice.]

Radiated EMI, cont'd.

This document establishes minimum performance requirements and methods of test for mobile antennas mounted on vehicles used by law enforcement agencies, and deals with antenna characteristics that determine the suitability and effectiveness of antennas for law enforcement use. As a result, only the following four frequency bands are considered: 25 to 50 MHz, 150 to 174 MHz, 400 to 512 MHz, and 806 to 866 MHz. This standard supersedes NILECJ-STD-0205.00, Mobile Antennas.
[Contact: Richard G. FitzGerrell, (303) 497-3737]

Kanda, M., and Wyss, J.C., **Evaluation of Off Axis Measurements Performed in an Anechoic Chamber.**

The performance of a rectangular radio-frequency anechoic chamber is measured when the device under test is not on the center line of the launch antenna. An electrically small field probe is repeatedly scanned longitudinally away from the launch antenna and into the chamber. With each scan, various parameters are changed, including: 1) horizontal and vertical position of the probe with respect to the center line of the launch antenna; 2) frequency; and 3) type of launch antenna. With the probe located 1 m off the center line and scanning between 2 to 6 meters from the launch horn, the uncertainty due to being off the center line ranges from ±1 dB at 250 MHz to ±5.0 dB at 800 MHz and above. If the probe is within ±50 cm of center line, the uncertainty is no more than ±1.5 dB at 800 MHz; and for ±25 cm of center line, the uncertainty is further reduced to ±0.5 dB at 800 MHz.
[Contact: Motohisa Kanda, (303) 497-5320]

Masterson, K., **A Photonic Electric Field Probe for Frequencies up to 2 GHz**, to be published in the Proceedings of the SPIE Conference on Fiber Optics, Optoelectronics, and Laser Applications in Science and Engineering, Cambridge, Massachusetts, September 24, 1986.

A photonic electric field probe using the Pockel's effect in bulk $LiNbO_3$ is described. It was used to measure electromagnetic fields from 10 to 100 V/m. The observed frequency response was flat up to 1.6 GHz and extended beyond 2 GHz. Over the majority of the frequency range, field strengths down to about 6 V/m should be detectable above the noise floor when using a 10-kHz detection bandwidth. Present experimental results indicate a linear dynamic range for the probe of approximately 30 dB. Increasing the optical carrier power and lowering the system noise floor is expected to improve the dynamic range to above 50 dB.
[Contact: Keith D. Masterson, (303) 497-3756]

Randa, J., and Kanda, M., **A Lattice Approach to Volumes Irradiated by Unknown Sources**, NBS Technical Note 1303 (October 1986).

We suggest an approach to the characterization of electromagnetic environments irradiated by unknown sources. The approach is based on the numerical solution of Maxwell's equations subject to the constraints imposed by the measured values of the field at a small number of measurement points and by boundary conditions. A thorough examination is presented of two methods for the numerical solution. The examples attempted demonstrate the approach, but reveal that neither technique is fully successful. Possible future directions are suggested.

[A paper based on the contents of this Technical Note is scheduled for presentation at the Seventh Symposium and Technical Exhibition on EMC (Zurich, Switzerland, March 1987) under the title "A Lattice Approach to Environments Irradiated by Unknown Sources" and will appear in the proceedings of that Symposium. A second paper based on this material has been submitted to the IEEE

Radiated EMI, cont'd.

Transactions on Electromagnetic Compatibility with the title "A New Approach to Volumes Irradiated by Unknown Sources."] [Contact: James P. Randa, (303) 497-3150]

Conducted Electromagnetic Interference

Recently Published

Key, T.S., and Martzloff, F.D., **A Consensus on Powering and Grounding Sensitive Electronic Equipment**, Industry Applications Society Annual Meeting, Denver, Colorado, September 29-October 3, 1986, pp. 1-7.

As sensitive electronic processing systems proliferate in our facilities, so do power-related problems. Efforts to alleviate these problems have ranged from installing expensive power conditioning equipment to applying special grounding techniques not found in conventional safe grounding practice. Understanding of what is actually going on has been lacking. We find elaborate power systems, modified from basic practice to the extent of being unsafe, that continue to be plagued with powering- and grounding-related problems. Out of this chaos we are persuaded to study and understand the complexities of the problem and to begin developing good practices. This is the objective of the IEEE Working Group on Powering and Grounding Sensitive Electronic Equipment, Standards Project P1100. We will introduce Project P1100, preview its scope and technical content and, most importantly, invite participation in this seriously needed consensus standard activity.
[Contact: Francis D. Martzloff, (301) 975-2409]

Martzloff, F.D., **Surge Suppressors and Clamps**, Proceedings of EMC EXPO 86, International Conference on Electromagnetic Compatibility, Washington, DC, June 16-19, 1986, pp. E01.1-E01.7.

The paper presents a review of technologies developed for surge suppressor devices used in electronic circuits. Three generic types are described: crowbars, varistors, and avalanche diodes. The significant differences in their performance characteristics are pointed out, together with guidance on proper application and measurements.
[Contact: Francois D. Martzloff, (301) 975-2409]

ADDITIONAL INFORMATION

Lists of Publications

Gibson, K.A., Page, J.M., and Miller, C.K.S., **A Bibliography of the NBS Electromagnetic Fields Division Publications**, NBSIR 85-3040 (February 1986).

This bibliography lists publications of the National Bureau of Standards' Electromagnetic Fields Division for the period from January 1984 through September 1985, with selected earlier publications from the Division's predecessor organizations.
[Contact: Kathryn A. Gibson, (303) 497-3132]

Kline, K.E., and DeWeese, M.E., **Metrology for Electromagnetic Technology: A Bibliography of NBS Publications**, NBSIR 86-3048 (June 1986).

This bibliography lists the publications of the personnel of the Electromagnetic Technology Division of NBS in the period from January 1970 through December 1985. A few earlier references that are directly related to the present work of the Division are included.
[Contact: Kathryn E. Kline, (303) 497-3678]

Palla, J.C., and Meiselman, B., **Electrical and Electronic Metrology: A Bibliography of NBS Electrosystems Division Publications, NBS List of Publications 94** (January 1987).

This bibliography covers publications of

Lists of Publications, cont'd.

the Electrosystems Division, Center for Electronics and Electrical Engineering, NBS, and of its predecessor sections for the period January 1963 to January 1987. A brief description of the Division's technical program is given in the introduction.
[Contact: Jenny C. Palla, (301) 975-2220]

Walters, E.J., **Semiconductor Measurement Technology: A Bibliography of NBS Publications for the Years 1962-1986,** NBSIR 87-3522 (February 1987).

This bibliography contains reports of work performed at the National Bureau of Standards in the field of Semiconductor Measurement Technology in the period from 1962 through December 1986. An index by topic area and a list of authors are provided.
[Contact: E. Jane Walters, (301) 975-2050]

1987 CEEE CALENDAR

July 28-30 (Vail, CO)

Short Course on Optical Fiber Measurements. This course is sponsored by the National Bureau of Standards and the University of Colorado with the cooperation of members of industry who serve as faculty together with staff from the Electromagnetic Technology and Electromagnetic fields Divisions. The course is intended for scientists and engineers involved in optical fiber characterization and emphasizes concepts, techniques, and apparatus used in measuring engineering parameters of telecommunications-grade fibers.

The following major topic areas are addressed: optics for communications, emphasizing geometric optics concepts; fiber properties and parameters; index-profile measurements; fiber bandwidth measurements in the frequency and time domains; fiber attenuation measurements; connector and splice losses; optical time-domain reflectometry concepts and applications; single-mode fibers; statistics and error analyses, measurement uncertainties; and fibers for sensors. [Contact: Office of Conference Services, University of Colorado (303) 492-8630; Robert L. Gallawa (303) 497-3761; or Matt Young (303) 497-3223]

September 14-16 (Research Triangle Park, NC)

VLSI and GaAs Packaging Workshop. This Workshop is co-sponsored by the Components, Hybrids, and Manufacturing Technology Society of IEEE and NBS; attendees are expected to be knowledgeable in the field and to participate in discussions. Topic areas include: VLSI and wafer scale package design (characterization and implementation, cost and performance driven solutions); package thermal design (characteristics, results, and issues); package interconnection options (wire bonding, TAB, flip nection options (wire bonding, TAB, flip chip, or optical); GaAs IC packaging (high speed packaging considerations); package electrical issues (reduction of parasitics and improvements in electrical performances); integrating package design (from die to system, including assembly and test issues); VLSI package materials advancements; die-attach solutions for large chips; new failure mechanisms in VLSI packaging. [Contact: George G. Harman, (301) 975-2097]

September 22-25 (Boulder, CO)

Noise Measurement Seminar. This four-day course is presented and hosted by the Electromagnetic Fields Division in cooperation with representatives from industry and the NBS Time and Frequency Division. It is intended for practicing noise metrologists and technical managers responsible for systems in which accurate measurements of thermal and phase noise are important. Attendees will learn the most important precautions to take in making accurate noise measurements and will receive a set of notes that are suitable for use in solv-

1987 CEEE Calendar, cont'd.

ing precision noise measurement problems. Course topics include reference thermal noise sources; thermal noise measuring systems and techniques; phase noise; and the problems of measuring thermal noise in passive components, amplifiers, and communication systems.

The course design combines formal lectures on theory presented by NBS staff and industry experts with demonstrations in NBS laboratories and demonstrations of commercial equipment. A special feature of the Seminar is the opportunity each day for attendees to share their experiences in solving specific problems or their insights on practical noise measurement issues through short presentations to the assembled group. Time is scheduled for group discussions of these presentations and other topics raised by the Seminar. [Contact: Sunchana Perera (303) 497-3546]

September 23-25 (Gaithersburg, MD)

Workshop on the Role of Optics in Power System Electrical Measurements. This Workshop is sponsored by NBS, the Bonneville Power Administration (BPA), the Electric Power Research Institute (EPRI), and the Empire State Electric Energy Research Corporation (ESEERC) and is intended for research and development engineers in utilities and in companies that supply equipment to the utility industry. The objective of this workshop is to identify anticipated opportunities for improved measurement techniques that should arise as power systems individually and collectively evolve to meet the needs of the 1990s. Presentations will stress the design and testing of optical systems for 60-Hz voltage or current measurement; the interfacing of electronic or optical components with existing metering and control systems; opportunities for new measurement hardware resulting from increased automated control of power systems and of the testing of power system components; and optical techniques for the measurement of electric and magnetic fields in power systems or system components. The results of an NBS study evaluating optical techniques for power-system electrical measurements and carried out in agreement with BPA, EPRI, and ESEERC will be presented as an invited keynote. [Contact: Robert E. Hebner, (301) 975-2403]

October 26-28 (Boulder, CO)

Symposium on Optical Materials for High Power Lasers (Nineteenth Boulder Damage Symposium). This Symposium is cosponsored by the National Bureau of Standards, the American Society for Testing and Materials, the Air Force Office of Scientific Research, the Office of Naval Research, and the Defense Advanced Research Projects Agency and constitutes a principal forum for the exchange of information on the physics and technology of materials for high-power lasers.

Topics to be discussed include new materials, bulk damage phenomena, surface and thin-film damage, design considerations for high-power systems, and fundamental mechanisms of laser-induced damage. Proceedings of the Symposium will be published (Note: The collection of Symposium proceedings contains information on optics for all aspects of high-power/high-energy lasers, including environmental degradation, durability, fabrication, material growth and deposition processes, and testing). [Contact: Susie A. Rivera (303) 497-5342]

December 10-11 (Gaithersburg, MD)

Power Semiconductor Devices Workshop. This Workshop, sponsored jointly by IEEE and NBS, is intended to bring together for interactive participation those actively working in the field of power semiconductor devices. It will be held in conjunction with the 1987 IEEE International Electron Devices Meeting in Washington, DC. Four specific topic areas have been selected, based on the response to a questionnaire sent to over

1987 CEEE Calendar, cont'd.

200 power device researchers worldwide. They are: power and high voltage integrated circuits, discrete devices, device modeling, and packaging. Attendees are expected to be prepared to contribute to the development of responses to specific questions that arise in the context of the particular topic areas; a final schedule identifying the topic areas should be available at the end of October. [Contact: David L. Blackburn, (301) 975-2053]

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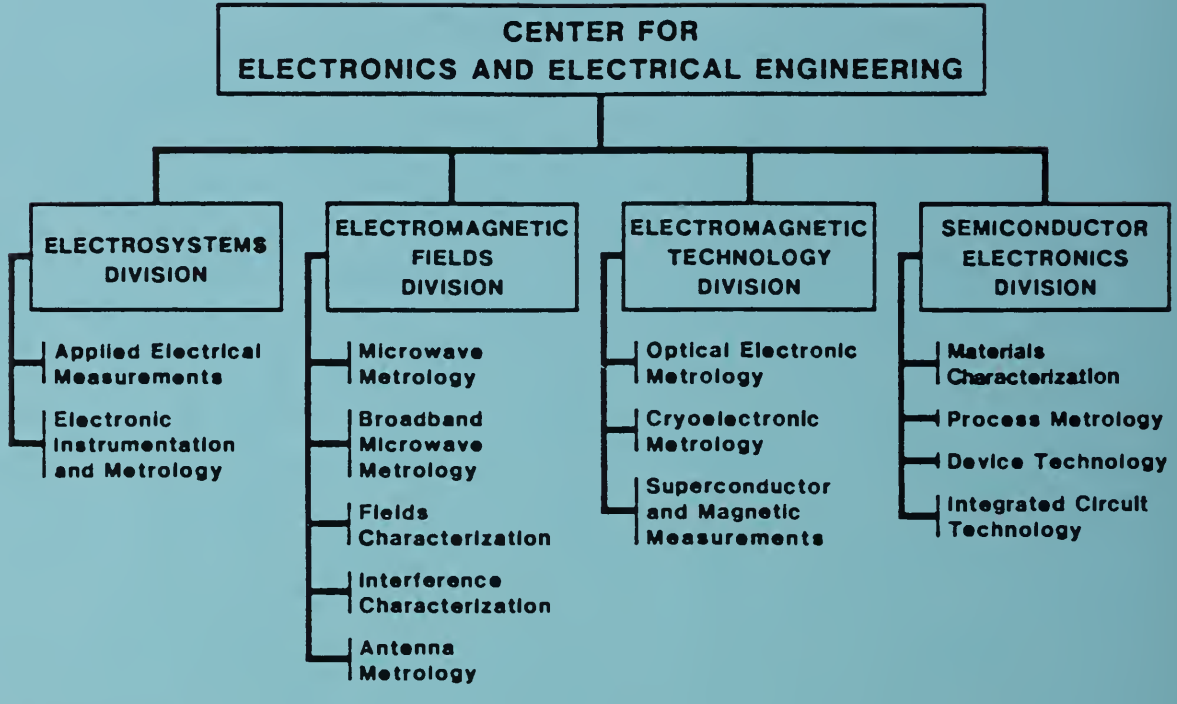

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